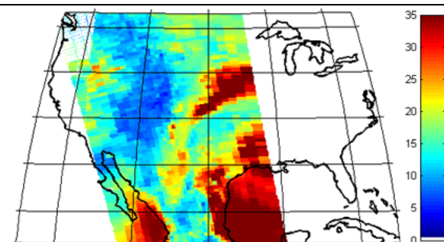
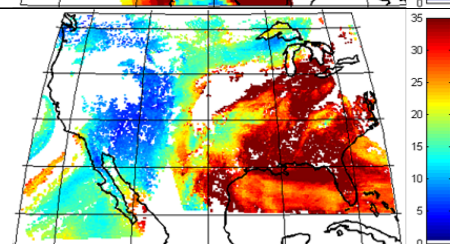
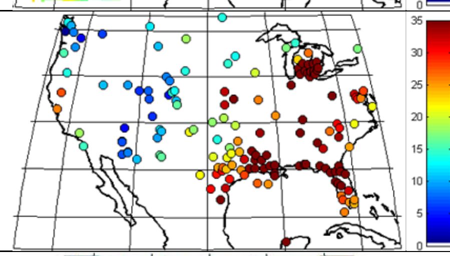
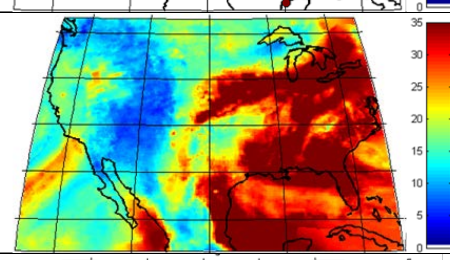
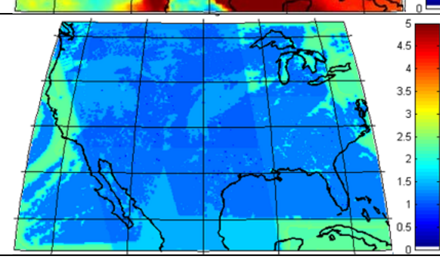
Colorado State University
Center for Geosciences/Atmospheric Research (CG/AR)
Quarterly Report No. 21
by T.H. Vonder Haar and Collaborators

Reporting period: April 1 – June 30, 2011

Cooperative Agreement #W911NF-06-2-0015

Input #1: MIRS Total Precipitable Water (mm)	
Input #2: GOES Sounder Total Precipitable Water (mm). White areas are obscured by clouds.	
Input #3: GPS Total Precipitable Water (mm)	
Output #1: Total Precipitable Water (mm) produced by universal kriging of the above three input fields.	
Output #2: Uncertainty estimate produced by universal kriging (mm). Note change of scale.	

From the research of Dr. Stan Kidder and Mr. John Forsythe. See details of their work under the Remote Sensing of Battlespace Parameters Theme.

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Overview

All CG/AR projects were recently presented at the Annual CG/AR Program Review in March 2011.

Dr. Jones continued support of the NPOESS MIS Performance Team (MPT) and the DoD Soil Moisture Working Group through several telecons. Dr. Jones also participated in a telecon with the Army on use of the MyWIDA Tactical Decision Aid (TDA) for use in surface soil moisture "ponding" for DoD military mobility applications. I n Prof. Julien's group, Andrew Steininger presented his dam overtopping results applied toward the California Gulch catchment in central Colorado. These new results are currently being compiled and analyzed. Prof. Niemann and Christopher Fields performed new soil moisture EOF analysis for several case study sites, they will begin to add new vegetation pattern data to the analysis. Prof. Niemann also visited the ERDC at Vicksburg, MS and gave an oral presentation there.

Dr. Noh's research team submitted a manuscript to the Journal of Geophysical Research on the Cloud Layer Experiment (CLEX) results. Dr. Seaman presented a poster to the 2011 Joint CALIPSO-CloudSat Science Team Meeting in Montreal. Drs. Miller and Haynes created a prototype 3-D view of clouds using CloudSat data sets with GOES cloud imagery. This was tested on Super Typhoon Choi-Wan over the east Pacific in 2009. An abstract of this work was submitted to the CloudSat Science Team meeting.

Dr. Fletcher ran some non-Gaussian Lorenz 1963 model experiments looking at predictability and stability issues within the non-Gaussian data assimilation techniques that he recently developed. Several CG/AR individuals also assisted with the Data Assimilation course in the Department of Atmospheric Sciences.

Mr. Sam Atwood, a student in Prof. Kreidenweis' group, was awarded a Naval Research Enterprise Internship Program (NREIP) through the ASEE. They continued their collaborations with Dr. Jeff Reid at NRL-Monterey. Through external supportive funds, Prof. Reising's group gained a new postdoc, Dr. Xavier Bosh-Lluis. Their group also started worked on the HUMidity Experiment (HUMEX11) at the ARM-CART site near Lamont Oklahoma and presented that work at several locations.

Prof. Vonder Haar and Mr. Gavin Roy continued their studies on land surface modeling impacts of alternative energy sources using the NASA Land Information System (LIS). Prof. Azimi's group focused on generating a realistic synthetic dataset to test the performance of their new methods. Those new results were presented at the CG/AR review by Mr. Soheil Kolouri.

Prof. Cotton submitted the recent MS thesis work of his student, Mr. Geoffrey Krall, as a manuscript to *Atmospheric Chemistry and Physics*. Prof. Prof. van den Heever's student Mr. Robert Seigel, has created a very innovative interactive land surface-dust lofting for experiments using the RAMS modeling system, to examine the interactions of dust with the cold pool formation and outflows of supercells. Several manuscripts are in progress.

Dr. Andrew S. Jones
Senior Research Scientist

For more information on the DoD Center for Geosciences/Atmospheric Research at Colorado State University, please access our web page at http://www.cira.colostate.edu/research/dod/geosci.php

Colorado State University
Center for Geosciences/Atmospheric Research
Scientific Interactions May 2006 to Present

- Sonia Kreidenweis and Kelley Johnson with Doug Westphal, Piotr Flatau, and Marcin Witek (NRL/Monterey)
- Tom Vonder Haar and others with Mr. Robert Brown (ARL)
- Tom Vonder Haar and CG/AR researchers with Dr. James Cogan (ARL)
- Milija Zupanski and others with Jeff Tilley (UND)
- Andy Jones and Cindy Combs with Gary McWilliams (ARL) and Li Li (NRL)
- Steven Fletcher with Carolyn Reynolds (NRL), Dale Barker (NCAR), Brian Ancell (Univ. Washington), Ron Errico and others (NASA Goddard), and international colleagues
- Stan Kidder with Arlin Krueger (Univ. Maryland-Baltimore County)
- Steven Fletcher with Clarke Amerault (NRL)
- Andy Jones, Laura Fowler, Steven Fletcher, Manajit Sengupta, Scott Longmore, Tarendra Lakhankar, and Curtis Seaman with Dale Barker, Hans Huang, Qingnong Xiao, Jenny Sun, and Zhiquan Liu
- Large and small group interactions at the Annual Review, held at CSU/Fort Collins, including:

  Tom Vonder Haar, Ken Eis, Loretta Wilson, et al. with DoD Review Panel and invited attendees

  Adam Kankiewicz with Pam Clark (ARL) and Ted Tsui (NRL)

  Stan Kidder and Jeff Jorgeson (ERDC)

  John Forsythe with Ted Tsui (NRL)

  Pierre Julien and James Halgren with Jeff Jorgeson (ERDC)

  Sonia Kreidenweis with Ron Pinnick (ARL)
- Steven Fletcher with Profs. Nancy Nichols and Alan O’Neil (Data Assimilation Research Centre, UK)
- Steven Fletcher with Dr. Amos Lawless (Department of Mathematics at the University of Reading) and Dr. Eric Andersson (ECMWF)
- Tom Vonder Haar with Patricia Phoebus, Joe Turk, Jerry Schmidt, Nancy Baker and Craig Bishop (NRL)

- Tom Vonder Haar with Philip Durkee (NPS)
- Mahmood Azimi with Mike Mungiole, Alan Wetmore, John Noble, Pam Clark, Sandra Collier and Dave Marlin (ARL)
- Curtis Seaman with Nancy Baker and others (NRL)
- Andy Jones and Steve Fletcher with Dale Barker (NCAR); Dennis Garvey, Jim Cogan, Alan Wetmore (ARL); Tim Nobis (AFWA)
- Yoo-Jeong Noh and Curtis Seaman with David Hudak (Environment Canada)
- CG/AR researchers and graduate students with James Cogan (ARL/WSMR)
- Steve Miller and Andy Jones with Michael Wynne (Secretary of the Air Force)
- Andy Jones with Gary McWilliams (ARL)
- Andy Jones with Dr. Ye Hong (Aerospace)
- Andy Jones with Mr. John Eylander (AFWA)
- Andy Jones with Dr. White (NOAA/ESRL)
- Andy Jones and Steven Fletcher with Bob Dumais (ARL)
- Andy Jones with Gary McWilliams (ARL)
- Andy Jones with Dr. Tom Greenwald (Univ. Wisconsin)
- Michael Coleman with Rick Shirkey (ARL)
- Andy Jones with Brian Skahill and Mike Follum (ERDC/CHL)
- Andy Jones and Adam Carheden with Rick Shirkey
- John Forsythe and Eric Guillot with Bob Dumais (ARL-White Sands Missile Range)
- John Forsythe with Lt. Col Vincent Rees (AFWA)
- Andy Jones with James Cogan (ARL)
- Andy Jones with Gary McWilliams (ARL), George Mason (ERDC), Jim Cogan (ARL) and Dr. Li (NRL)
- Stan Kidder with Prof. Phil Durkee (NPGS)
- Sonia Kreidenweis with Prof. Cathy Cahill (Univ. Alaska-Fairbanks)
- Andy Jones with John Eylander (AFWA)
- Andy Jones with Susan Frankenstein (CRREL)
- Sam Atwood with Pam Clark and others (ARL)
- Andy Jones with John Eylander (AFWA)
- Prof. Jeff Niemann with George Mason (GSL/ERDC)

- Yoo-Jeong Noh with Peter Rodriguez (Environment Canada)
- Yoo-Jeong Noh with Dr. G. Liu (Florida State University)
- Andy Jones, Tom Vonder Haar, Stan Kidder, Sonia Kreidenweis and Sam Atwood, Steve Reising, John Forsythe, Loretta Wilson with Dr. James Cogan (ARL), 3-day visit to CG/AR
- Sonia Kreidenweis with Prof. Cathy Cahill (Univ. Alaska-Fairbanks)
- Sonia Kreidenweis with Dr. Jeff Reid (NRL-Monterey)
- Andy Jones with Dr. Rick Shirkey (ARL)
- Sam Atwood at NRL-Monterey (hosted by Dr. Jeff Reid)
- Andy Jones, Sue van den Heever and Rob Seigel with Dr. Robert Haehnel (Army Cold Regions Research and Engineering Laboratory)
- Prof. Steve Reising with Dr. David Turner (NOAA National Severe Storms Laboratory)

Research Theme: Hydrometeorology

Administrative

None this period.

Research activity and/or results

Dr. Andrew Jones
Continued activities related to support for the NPOESS MIS Performance Team (MPT) land team.

In addition, he responded to several follow-up items from the CG/AR Annual Program Review, which was held March 8 and 9.

Andy Jones collaborated with Dr. Richard Shirkey and Gary McWilliams at ARL/BED and with other Army individuals to discuss the implementation of the MyWIDA-Log ponding application.

Prof. Pierre Julien and Andrew Steininger
Andy has continued his modeling research concerning dam break and dam overtopping. Andy has been applying the TREX watershed model to the California Gulch catchment in central Colorado. Previous model set up work has been used as a starting point for dam break and overtopping simulations. Artificial dams have been inserted into the modeled watershed and many successful simulations have been run. The results of these simulations have provided much insight into the previously unknown range of applicability of the TREX model to dam overtopping and large flood wave scenarios. The results of these model simulations have begun to be compiled and analyzed for quantitative as well as qualitative review.

Prof. Jeffrey Niemann and Christopher Fields
This project aims to develop a method to estimate ponded or saturated areas on a landscape for use in tactical decision aids such as MyWIDA. Major accomplishments made before the present quarter include: (1) development of a ponding method based on empirical orthogonal function (EOF) analysis of available space-time soil moisture datasets, (2) testing of this ponding method by developing and applying it to four available datasets including Tarrawarra, Tarrawarra2, Satellite Station, and Cache la Poudre. Under a companion project that was sponsored by the Engineer Research and Development Center (ERDC), a physical interpretation of the EOF method was also developed. This method allows identification of ponded areas in a manner similar to EOF method but requires computation of fewer topographic attributes and is more readily applied when data is limited. Thus, future research in this project is expected to build on this physical interpretation of the EOF method. In the previous quarter, Frederick Busch successfully defended his MS thesis, and Christopher Fields joined the project as a PhD student. The long-term objective for Mr. Fields participation in this project is to incorporate data for vegetation patterns (if available) into the ponding method.

During the current quarter, Mr. Fields continued to gain familiarity with the literature on topics related to the project objectives. These topics include: the physical processes governing the movement of moisture in the soil, available methods to measure soil moisture, observed topographic dependence of soil moisture patterns, representations of vegetation patterns based on remote-sensing measurements, and estimation of soil moisture from remote-sensing algorithms. Mr. Fields also began familiarizing himself with the software the implements the ponding method so that he will be able to implement enhancements in that software in the future. He also gained familiarity with the datasets that are available for model testing.

In the next quarter, Mr. Fields will begin a series of experiments to test the strengths and weaknesses of the current methodology in order to better identify how vegetation properties could benefit the results. Those experiments will also provide a foundation for his PhD dissertation proposal. He will also take his PhD qualifying exam in the next quarter.

Travel

Professor Niemann traveled to the US Army Corps of Engineers' Engineering Research and Development Center, Vicksburg, Mississippi, June 9-10 and gave an oral presentation.

Equipment/systems status

The proposed desktop computer purchase from the previous quarter was realized this quarter. This computer has the purpose of being a dedicated TREX modeling computer. It has proved to be a very appropriate and efficient platform for TREX modeling.

Research Theme: Clouds, Icing, and Aerosols Effects

Administrative

Salary support for Dr. Miller's role in the research topic CloudSat Extended Statistics ended April 30.

Research activity and/or results

Dr. Yoo-Jeong Noh

C3VP/CLEX-10 satellite and aircraft data analysis

The manuscript that was submitted to Journal of Geophysical Research was secondly revised pursuant to a minor revision request from two reviewers and was accepted on June 30.

With Curtis Seaman, prepared a poster for the 2011 Joint CALIPSO-CloudSat Science Team Meeting in Montreal. CALIOP figures were plotted along the newly selected flight segments for three selected CLEX-10 cases.

Performed the detailed analysis of liquid and ice water content profiles using CLEX-10 data and examined all the segments (10 to 20 minutes) of the airborne radar images of 28 flights provided by Peter Rodriguez (Environment Canada) in order to find profiles through a cloud layer (see Figure 1). CLEX-9 data were also utilized to increase the number of data samples. Curtis Seaman and Yoo-Jeong Noh have begun to write a manuscript to be submitted to GRL or JAMC.

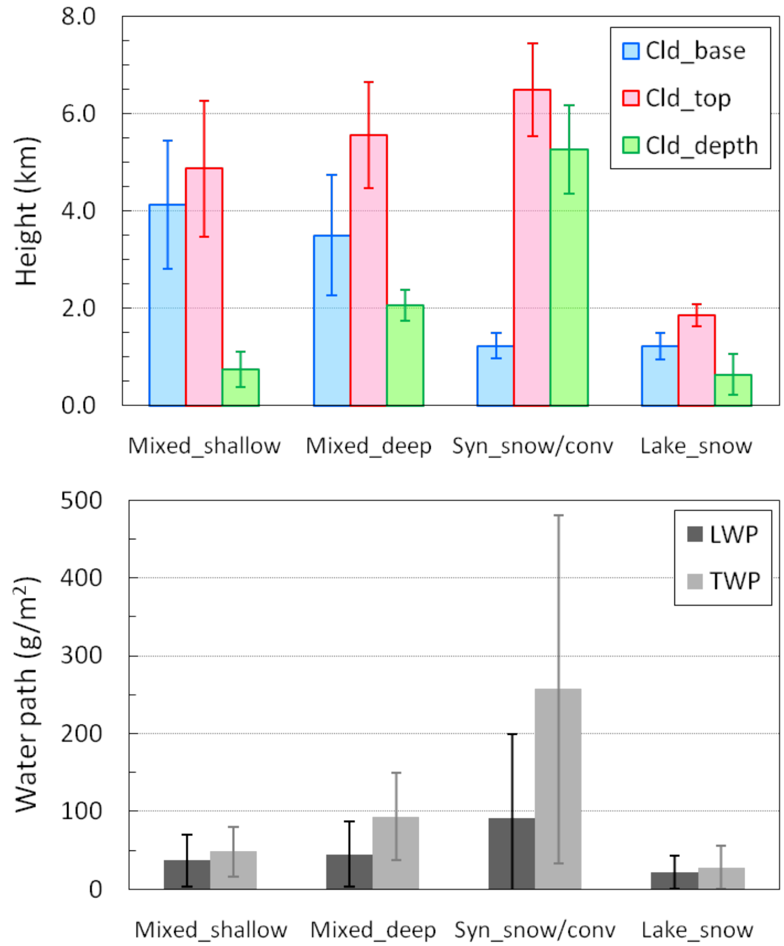


Figure 1. Averages of cloud base, top, and depth with LWP and TWP for 41 profiles examined using radar and flight tracks that are separated into four groups: shallow mid-level, mixed-phase (less than 1 km thick); deep mid-level, mixed-phase (more than 1 km thick); synoptic snow/deep convective mixed-phase clouds with precipitation at the surface (e.g. nimbostratus); and lake-effect snow clouds. Note that the sample numbers 20, 13, 5, and 3, respectively. The error bars represent each standard deviation among the means.

Dr. Curtis Seaman

Continued research on mixed-phase clouds and icing this quarter, working closely with Yoo-Jeong Noh. Work concluded on a second revision to the manuscript submitted to the Journal of Geophysical Research. After the first revision, reviewers asked for additional clarity on the limitations, errors and uncertainties in each of the observations (microphysical probes, airborne radar and lidar, and satellite retrieval algorithms) and improvements were made to the section of the paper outlining the errors introduced in radiative transfer simulations due to CloudSat's incorrect classification of liquid and ice. One reviewer recommended using the microphysical probe data to simulate what an airborne W-band radar would have observed if it had been on the aircraft during the first two intensive observation periods (IOPs) during CLEX-10, although our position was this suggestion was beyond the scope of our paper, and suitable as a study for a future manuscript. The revised manuscript titled, “Comparisons and analyses of aircraft and satellite observations for wintertime mixed-phase clouds” was re-submitted.

Results included in the manuscript were presented by Curtis at the CloudSat/CALIPSO Science Team Meeting, which was held in Montreal, Quebec, Canada, 15-17 June.

Lead by Dr. Noh, work began on a second manuscript based on C3VP/CLEX-10 data. This manuscript, tentatively titled, “In situ aircraft measurements of the vertical distribution of liquid and ice water content in mid-latitude mixed-phase clouds” summarizes the vertical distributions of liquid and ice throughout all clouds observed by the aircraft during C3VP/CLEX-10. Microphysical comparisons will be made between mid-level clouds, lake effect snow, and deep precipitating/synoptic snow cloud cases. The manuscript will be targeted toward Geophysical Research Letters, or a similar journal.

Dr. Steve Miller, John Forsythe, Phil Partain and John Haynes
Work this period focused on generating a prototype 3-D view of clouds using our algorithm developed to date. To date, quantitative validation of the extended cloud statistics technique has come in the form of data denial experiments along the CloudSat ground track. While observationally-based validation data for 3-D scenes is limited, we can take advantage of the understood structure of organized cloud systems such as tropical cyclones to assess performance qualitatively. Some additional quantitative validation for off-ground-track data will be attempted with available surface-based data (e.g., ARM sites).

We tested our 3-D cloud scene generation technique on Super Typhoon Choi-Wan over the east Pacific in 2009. As indicated in the Figure 2 (next page), CloudSat flew directly over the eye of the storm, providing a useful set of profile data applicable to many other portions of the symmetric system.

Figure 3 shows an estimate of cloud vertical extent for the uppermost layer, produced at an oblique angle to the CloudSat track (shown in purple). This is the first example of the algorithm being applied to clouds not residing along the CloudSat track. Since the statistical extrapolations are done on a cloud-class-dependent basis, the ‘cloud type reconciliation’ (relating CloudSat-derived cloud classes to the GSIP-MODIS-derived cloud classes) was a necessary step here. The eye and the deep convective core of the storm, as well as some spiral rain band cross-sections, are well-depicted and consistent with expected storm structure for these areas. Most of the outer cirrus and overlap (cirrus over a lower cloud) cloud classes show higher bases, with some exceptions. The issues here are most likely related to misclassification between cirrus and opaque ice, resulting in some “cirrus” clouds having bases near the surface. Other cross sections (not shown here) have been created for a full 360 rotation around Choi-Wan’s eye. This capability will be applied to other weather systems where our *a priori* knowledge is less solid. A full 3-D animation of the Choi-Wan case study can be viewed at:
http://amsu.cira.colostate.edu/extended/rotatem20/.

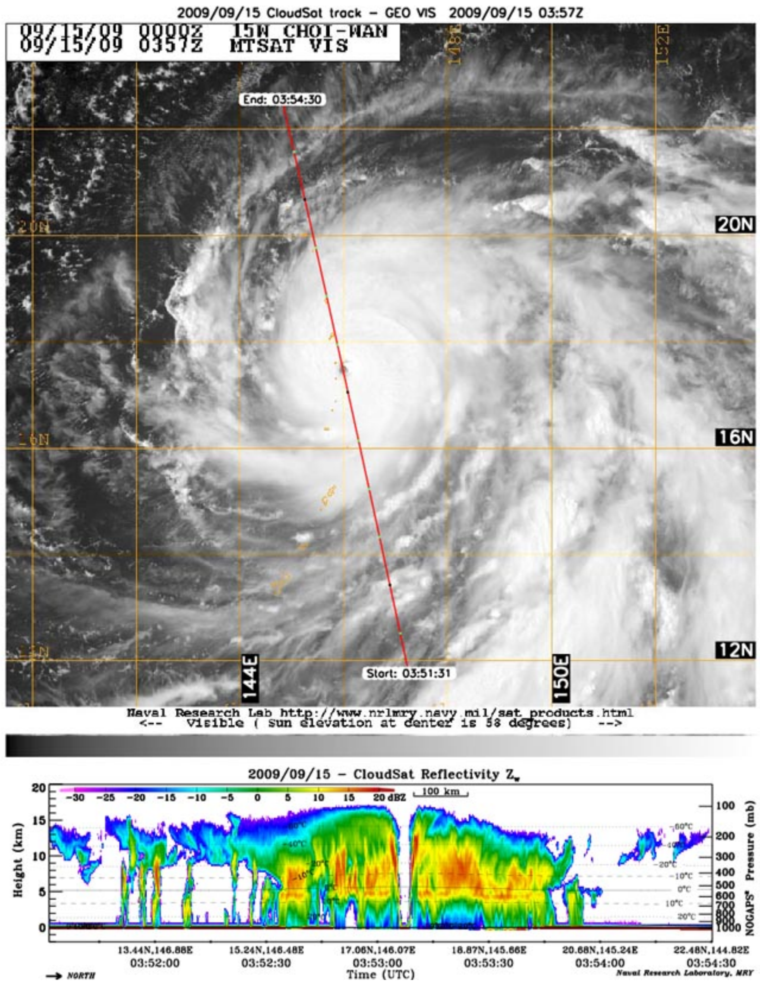


Figure 2. Ground track of CloudSat (red) over supertyphoon Choi-wan, with corresponding radar reflectivity cross-section.

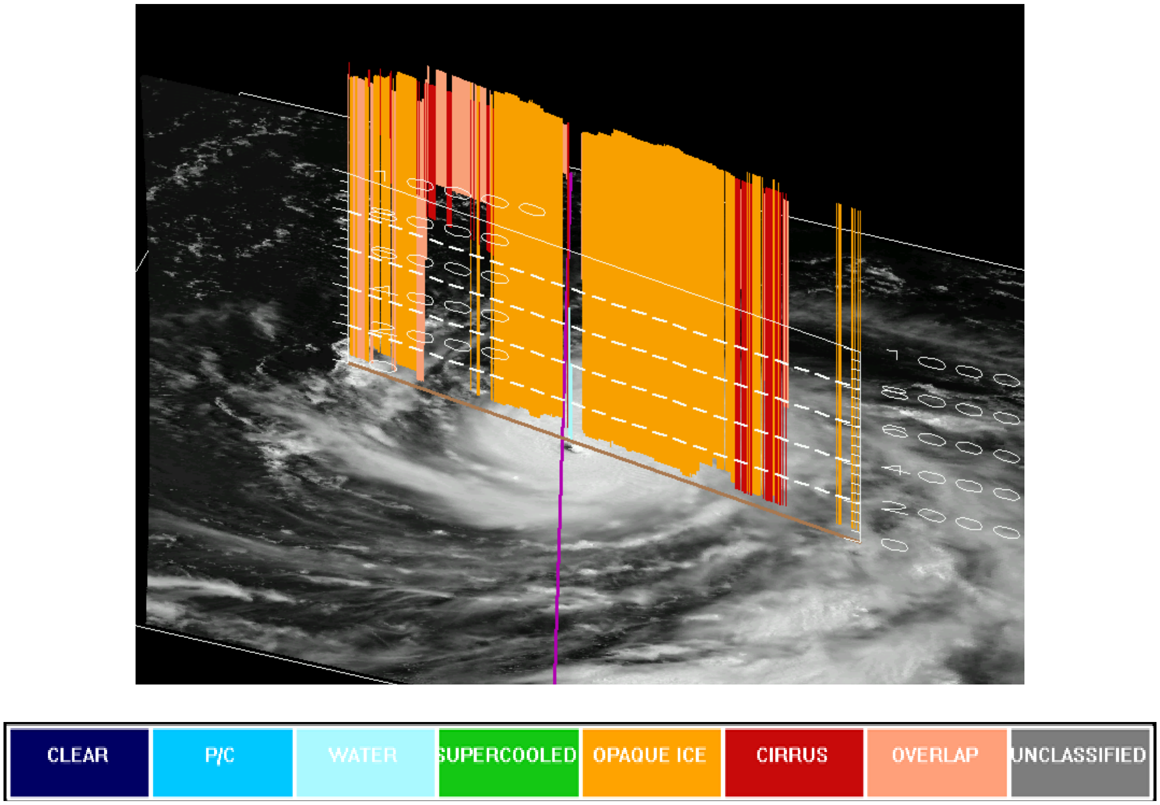


Figure 3. First 3-D reconstruction of Typhoon Choi-wan (September 15, 2009). Cloud vertical occurrence of the uppermost cloud layer oblique to the CloudSat track (purple line) is shown, overlain on the MODIS visible image. The cloud thickness is colored by the GSIP class at cloud top from MODIS. Note that the opaque ice class (yellow) is indicative of deep convection in the core of the typhoon, while the red and salmon colored classes (cirrus and overlap) indicate either high ice clouds or sometimes deep convection. Cloud heights in meters with dashed lines at 2000 m intervals.

The Choi-Wan case study enlists several new techniques we are experimenting with relating to how many CloudSat data points to consider when making a prediction. The techniques were developed upon realizing that the original approach was potentially giving too much weight to points that were far removed from the test location. Although in a statistical sense this should not matter if the variance of cloud level is low (in which case, distant points hold relevant information), there are still physically-based reasons to preferentially weight the closest neighbors more. Details of the new techniques for data selection and their impact on the skill of prediction will be described in upcoming progress reports. Results will be presented statistically to gauge overall performance between the various techniques and in comparison to simpler methods for different seasons and locations.

An abstract entitled "Statistical Extrapolation of Vertically Resolved Cloud information from CloudSat / CALIPSO Observations to Regional Swaths" was submitted to the CloudSat Science Team meeting, held in Montreal, Canada June 15-17.

New logic for defining the number of common-cloud-class points to use, and the value of the search radius for finding them, has been developed and will be implemented in the research algorithm.

Work continued on a journal paper for this research.

John Forsythe
In addition to participation in the above research, two major research efforts were performed during this period: 1) Final edits on the journal paper "How Total Precipitable Water Vapor Anomalies Relate to Cloud Vertical Structure" (Forsythe, Dodson, Partain, Kidder and Vonder Haar authors), which is now in review at the AMS *Journal of Hydrometeorology;* and 2) Collaboration with Eric Guillot on his journal paper which encapsulates his M.S. thesis.

A number of DoD-relevant applications of this work were cited in the TPW anomaly paper, such as cloud base estimation from infrared or visible (i.e. most sensitive to cloud top) imagery, aerial reconnaissance in pristine atmospheres, and model performace evaluation. Figure 4 (next page) shows how cloud vertical occurrence changes with Total Precipitable Water anomaly in three regions: The North Pacific (NPAC), the tropical east Pacific (NINO), and the Mississippi Valley (MSVL). Results are shown for December, January and February of 2007 – 2009. Notice how clouds become deeper and more likely as TPW anomaly increases over NPAC and NINO. In essence, this work explores how a readily observable quantity (total precipitable water vapor) can be related to a very difficult to observe quantity (cloud vertical occurrence). More details are presented in the paper.

Collaborated as third author on Eric Guillot's paper "Evaluating satellite-based cloud persistence and displacement nowcasting techniques over complex terrain." The work compares several cloud nowcast techniques in the 2-4 hour forecast timeframe. This paper will be submitted to *Weather and Forecasting* later in the summer.

Worked with Phil Partain to implement the MODIS-GSIP cloud classifier into the CloudSat Data Processing Center core software. This supports the extended cloud work by enabling data-denial experiments for over 4 years of data along the CloudSat track.

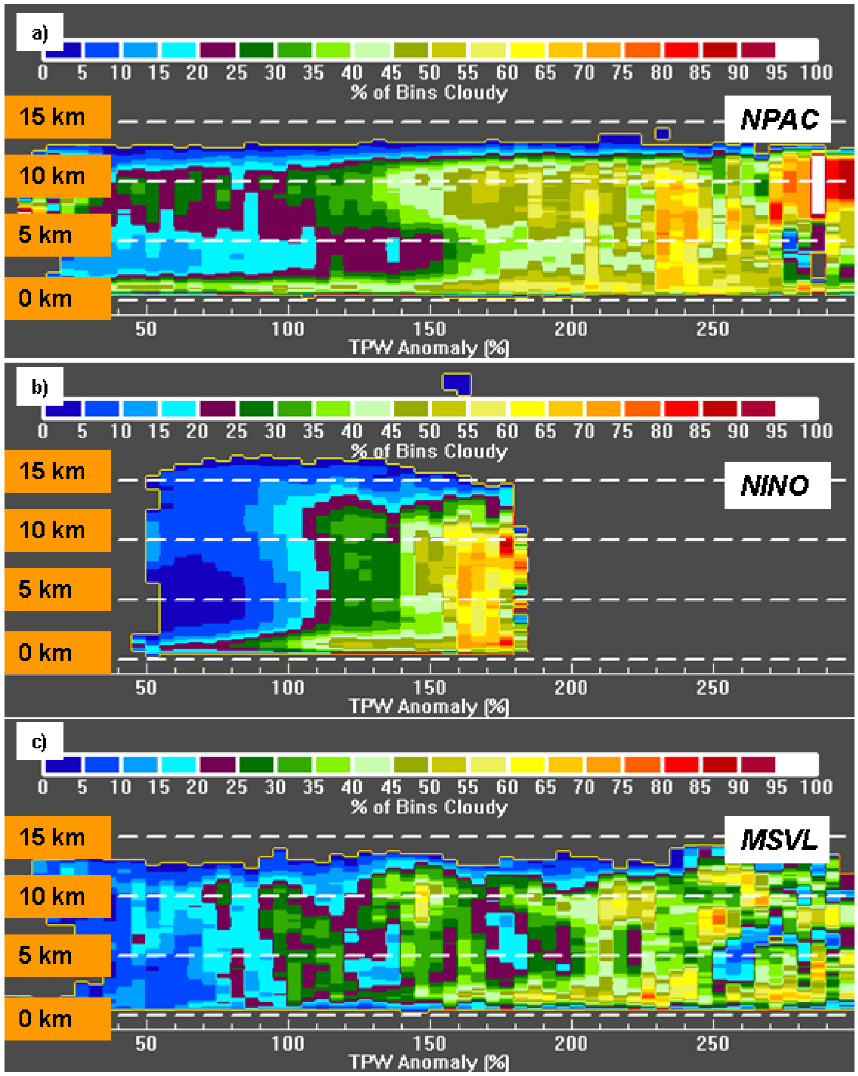


Figure 4. 2B-GEOPROF-Lidar vertical cloud frequency binned by TPW anomaly for DJF 2007-2009. The three study regions are shown (a) NPAC, (b) NINO and (c) MSVL. Horizontal dashed lines are height ASL at 5 km spacing.

Travel

Curtis Seaman traveled to Montreal, Quebec, Canada and presented a poster at the CloudSat/CALIPSO Science Team Meeting, which took place June 15-17.

Equipment/systems status

Nothing to report this period.

Research Theme: Environmental Modeling and Assimilation

Administrative

None this period.

Research activity and/or results

Dr. Steven Fletcher

Ran experiments with the forecastability of the non-Gaussian Lorenz 1963 model looking at short, medium and long range forecasts and the impact of different observational errors sizes and window lengths.

Assisted Eric Guillot edit the journal manuscript; assisted with the Data Assimilation course in the Department of Atmospheric Science, attending lectures and helping students with their literature reviews.

Travel

None this period.

Equipment/systems status

Nothing to report this period.

Research Theme: Urban and Boundary Layer Environment

Administrative

Mr. Gavin Roy, masters graduate student advised by Prof. Vonder Haar in the Department of Atmospheric Science, studying under a NSF Graduate Fellowship, has been associated with the Center due to his boundary layer and LIS research. Some summer salary and other costs not covered by the fellowship have been supported by CG/AR.

Sam Atwood transferred to non-GRA status for summer 2011 as he was awarded a Naval Research Enterprise Internship Program (NREIP) through the American Society for Engineering Education.

Dr. Xavier Bosch-Lluis joined the Microwave Systems Laboratory in the Electrical and Computer Engineering Department (Prof. Reising, Director) as a postdoctoral scholar. His salary is fully supported by synergistic funding external to CG/AR, but his background and expertise will aid the progress of the graduate student and this research task. Dr. Bosch-Lluis received his Ph.D. in March 2011 from the Universitat Politècnica de Catalunya (UPC), Barcelona, Spain. His academic and research advisor was Prof. Adriano Camps in the Department of Signal Theory and Communications at UPC.

Research activity and/or results

Prof. Thomas Vonder Haar and Gavin Roy

The research continues to focus on the effect of alternative energy sources on the atmospheric boundary layer, radiative balance, and regional hydrology. Gavin is using NASA's newly-developed Land Information System (LIS) to quantify the near-surface effect of replacing corn crops in many areas across the Midwest with switchgrass and miscanthus crops, grasses that have been found to be on average 50% more effective at being converted into biofuel than corn.

Prof. Sonia Kreidenweis, Sam Atwood and Lauren Potter

Sam Atwood and Lauren Potter continued their coursework toward their ATS M.S. degrees through the end of the Spring 2011 semester (May 2011). They also continued their research activities, in particular analysis of DRUM data from special studies at two southeastern Asia sites, obtained through Dr. Jeff Reid of NRL.

Research accomplishments during this time period:

1. Analysis of DRUM data from Lulin (South China Sea) and Singapore special studies.
2. Computation and analysis of trajectories to sites.
3. Initial development of case studies of pollutant, smoke, and dust transport, as seen in the data sets.
4. Further analysis of trajectory variables including precipitation and solar irradiation. Development of methods for data display.

Prof. Steven Reising, Swaroop Sahoo and Dr. Xavier Bosch-Lluis

Prof. Reising initiated and worked on a proposal and scientific plan for HUMidity EXperiment 2011 (HUMEX11), a field experiment to be conducted during the summer of 2011 at the Department of Energy's Atmospheric Radiation Measurement site near Lamont, Oklahoma. The field experiment was proposed to verify findings from our past research to increase the vertical resolution of retrieved water vapor profiles.

Prof. Reising presented a talk entitled "Measurement of Water Vapor Density Variations with Fine-Scale Spatial and Temporal Resolution using a Network of Ground-Based, Compact Microwave Radiometers" as the National Weather Center Seminar at the University of Oklahoma and NOAA's National Severe Storms Laboratory (NSSL), Norman, Oklahoma on June 14. He also discussed research collaboration on HUMEX11 with Dr. David Turner of NOAA NSSL during his visit to the National Weather Center.

Dr. Bosch-Lluis worked with Mr. Swaroop Sahoo to upgrade the Compact Microwave Radiometers for Humidity Profiling (CMR-Hs). As part of planning the HUMEX11 experiment, Dr. Bosch-Lluis proposed various scanning patterns for the three radiometers deployed during the field experiment. He also wrote software to control the positioner, which is used to aim each radiometer and scan to various azimuth and elevation angles.

Mr. Sahoo worked on upgrading the temperature control of the CMR-Hs. The temperature control module was upgraded for operation of the radiometer at 100°F because the ambient temperature of Lamont, Oklahoma during the summer is typically in the range of 80-110°F. He also worked on make the chassis of the radiometer more rugged and easier to control its temperature. The wide-angle (15-16° beamwidth) antenna of the Ball Aerospace radiometer was replaced with a box-horn array antenna of 3-4° beamwidth. This antenna beamwidth is useful to increase, i.e. improve, the resolution of the retrieved water vapor field.

Dr. Bosch-Lluis and Mr. Sahoo traveled to the Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Central Facility near Lamont, Oklahoma from 13-June-2011 to 15-June-2011 to test the Compact Microwave Radiometer for Humidity Profiling (CMR-H). The testing mainly involved determining that there was no significant radio frequency interference from various active remote sensing instruments deployed at the Central Facility as well as testing the instrument's upgraded temperature control subsystem. Prof. Reising, Dr. Bosch-Lluis and Mr. Sahoo were also involved in choosing the sites near Lamont for the deployment of the CMR-Hs for the HUMEX11 field campaign.

Prof. Mahmood R. Azimi-Sadjadi and Soheil Kolouri

This quarter's research was mostly focused on the following items:

(a) Generating a realistic synthetic dataset in order to better evaluate the performance of the developed methods. This was needed due to lack of *in-situ* measurements in the STINHO database. The data generation process has the following characteristics.
   - A fractal Brownian motion (fBm) based model [1] was used to simulate the 2D-wind and temperature profiles in space and time.
   - The simulated dataset contains, 500 snapshots of wind velocity and temperature in an area of size 300m*440m (the same area as that used in the STINHO dataset).

- The spatial resolution of this dataset is 1m and its time resolution is 1min.
- The codes for this simulation are implemented in a way to allow changing the time/space resolutions.
- 8 transmitters and 12 receivers were used as in the actual experimental setup for the STINHO data collection (see Figure 5). The time of arrivals (ToA's) were then calculated for all possible paths.

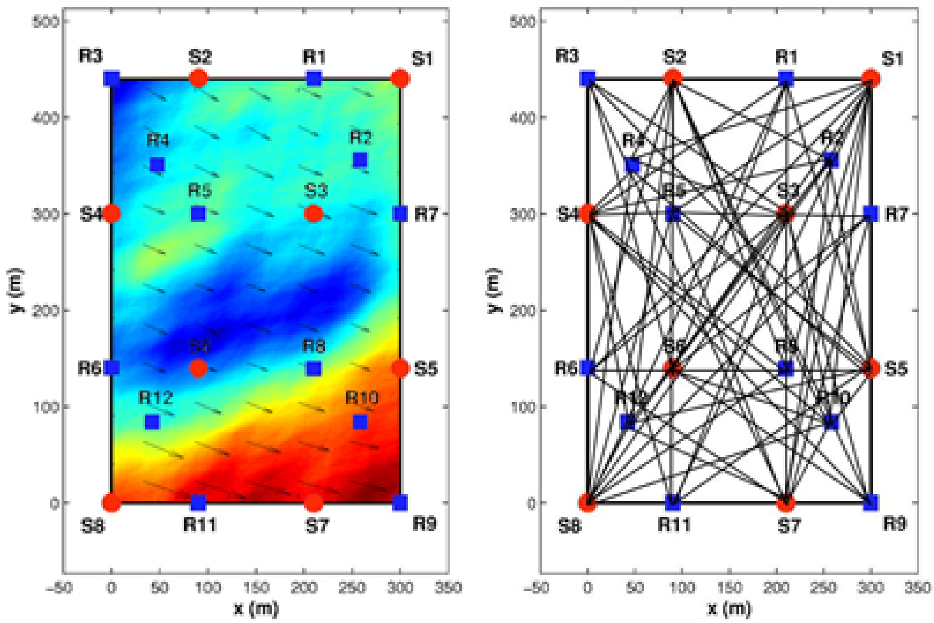


Figure 5. Wind and temperature profiles with transmitters and receivers positions (left); All possible paths (right).

(b) Implementing the developed Unscented Kalman Filter (UKF)-based state estimation algorithm on the simulated data to estimate the temperature and wind velocity components in each grid. The following steps are carried out.
  - The deployment area is partitioned into 4*8 grids as shown in Figure 6 where it is assumed that the fields (temperature and wind velocity components) are constant within each grid cell of size $75m * 55m$.
  - Calculate the length of each propagation path in each cell and reformulate the observation model based on each propagation path.
  - Iterate the proposed UKF-based state estimation on the simulated data several times for every one minute observation (i.e. fixed-point iteration).
  - Assessed the performance of the method and debugged the codes.

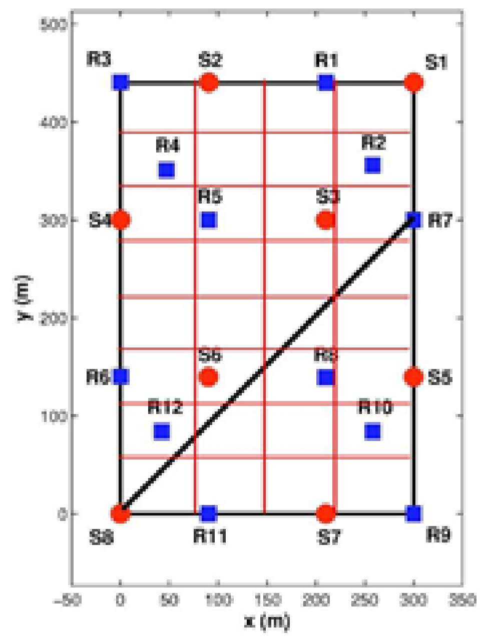


Figure 6. 4*8 Grid and a sample path from R7 to S8.

Brief Description of the Problem:

Acoustic tomography of the atmosphere attempts to reconstruct the temperature and wind velocity fields in a deployment area, based on acoustic travel times measured from various receivers deployed in the area. The travel time needed for an acoustic wave to propagate from a source to a receiver is a function of temperature, wind velocity (air flow) and humidity along the path. However, the effect of humidity on the travel time is somehow negligible and we have

$$T = T_{th}(1 + 0.511 * q) \tag{1}$$

where T_{th} is the thermodynamic temperature, T is the actual temperature in Kelvin and q is the specific humidity of the air, which is usually between 0 and 0.03 $kg\ kg^{-1}$ therefore we can write $T \approx T_{th}$.

Formulation of the problem

Considering a straight ray model the travel time is formulated as [2]:

$$\tau_n(t) = \int_{L_n} \frac{\mathrm{d}l_n}{c_{ray}(\mathbf{r},t)} = \int_{L_n} \frac{\mathrm{d}l_n}{c_L(\mathbf{r},t) + \mathbf{s}_n.\mathbf{v}(\mathbf{r},t)} \tag{2}$$

Here c_{ray} is the sound speed along the propagation path, r is the spatial vector, t is time, c_L is the Laplace sound speed which depends on thermodynamic temperature, s_n is the unit vector in the direction of propagation and v is the wind velocity vector.

In order to be able to solve the inverse problem we need to discretize (2), based on the grid we put on the field where the transmitters and receivers are deployed. This process yields

$$\tau_n(t) \quad = \quad \Sigma_{i=1}^{I}\Sigma_{j=1}^{J}\frac{d_n(i,j)}{c_L([i,j],t)+\mathbf{s}_n.\mathbf{v}([i,j],t)} \tag{3}$$

where $= 4$, $J = 8$ and $d_n(i,j)$ is the n^{th} propagation path length in cell (i,j) and $s_n.v([i,j],t)$ can be written as

$$\begin{aligned}\mathbf{s}_n.\mathbf{v}([i,j],t) \quad &= \quad \alpha([i,j],t)cos(\theta([i,j],t))cos(\phi_n) + \\ &\quad\ \alpha([i,j],t)sin(\theta([i,j],t))sin(\phi_n)\end{aligned} \tag{4}$$

where ϕ_n is the angle of n^{th} propagation path with horizontal line, $\alpha([i,j],t)$ is the amplitude of wind velocity and $\theta([i,j],t)$ is the angle of wind velocity in cell $[i,j]$.

In order to formulate the acoustic tomography problem as a state estimation problem, the unobserved state and observed measurement vectors are needed to be defined as follows.

$$\mathbf{x}_k = [\mathbf{c}_L(k), \boldsymbol{\alpha}(k), \boldsymbol{\theta}(k)]^T \longrightarrow \mathbf{c}_L(k) \ = \ [c_l([1,1],k), c_l([1,2],k), ..., c_l([I,J],k)]$$

$$y_k = [\ \tau_1(k), \dots, \tau_N(k)] \tag{5}$$

where N is the total number of paths. The dynamic of the process (state evolution equation) is unknown but the simplest model one can expect to describe this process is a random walk. Deploying a random walk model for process we can form the state estimation equations as

$$\begin{aligned}\mathbf{x}_k \quad &= \quad F(\mathbf{x}_{k-1}) + \mathbf{u}_k = \mathbf{x}_{k-1} + \mathbf{u}_k \\ \mathbf{y}_k \quad &= \quad H(\mathbf{x}_k) + \mathbf{v}_k\end{aligned} \tag{6}$$

Here $\mathbf{u}_k$ is the process noise and $\mathbf{v}_k$ is known as observation noise or measurement noise. Process noise and observation noise are assumed to be Gaussian random vectors with known mean and covariance matrices. $H(.)$ is defined based on the model in Eq. (3).

Results and Discussions

UKF [3] is then applied to generate state estimates using (6) for the synthesized data. To generate reasonable estimates of the covariance matrices for the process and observation noise a small number of data snapshots (twenty) were used. UKF algorithm starts from the mean field [4] at time zero with an initial estimate of the error covariance matrix P_{x_0}, and then iterates on each snapshot 5 times. The estimated state vector and covariance matrix at time k, $\hat{\mathbf{x}}_{k|k}$ and $P_{k|k}$, will be used as the initial state and covariance for UKF at time $k+1$. Figure 7 shows the result of temperature and wind field reconstructions for a sample snapshot. Looking closer at this result, two major problems can be observed. First of all, the reconstructed temperature seems to track the changes in the deployment area but with no spatial dependency among cells. Second, it can be observed that the reconstructed wind velocity is not tracking the actual wind velocity well enough.

The first problem can be attributed to the lack of any spatial-temporal dynamical model for our state evolution, as a simple random walk with no spatial-temporal dependency between the states was used. This will be addressed in the next quarter research. The second problem is also partly due to the same shortcoming and partly to not having an accurate estimate of the covariance matrix for $\mathbf{u}_k$. In addition, since UKF is reconstructing the fields simultaneously the accuracy of the temperature estimation will also affect the accuracy of the wind velocity estimation.

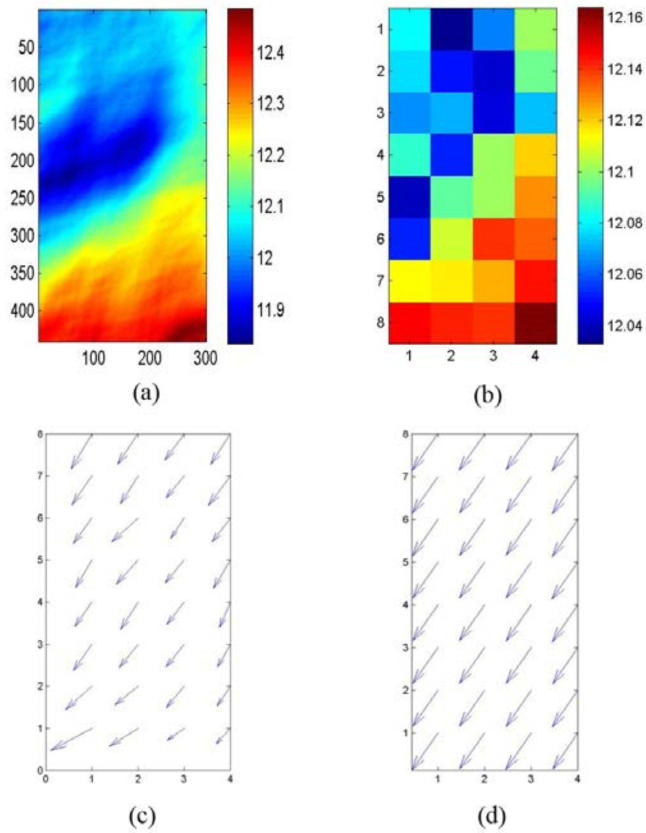


Figure 7. (a) Actual temperature field-synthesized data; (b) Reconstructed temperature field; (c) Actual wind velocity field-synthesized data; (d) Reconstructed wind velocity field.

Figure 8 shows (next page) the box plot of the error between the actual and reconstructed fields plotted for each 5 minutes (5 snapshots). These plots clearly show the fact that the UKF is converging.

References

[1] O. Khorloo, Z. Gunjee, and B. Sosorbaram, “Wind Field Synthesis for Animating Wind-induced Vibration,” *The International Journal of Virtual Reality*, vol. 10, no. 1, pp. 53-60, 2011.

[2] D. Keith Wilson and D. W. Thomson, “Acoustic tomographic monitoring of the atmospheric surface layer,” *Journal of Atmospheric and Oceanic Technology*, vol. 11, p. 751, 1994.

[3] S. J. Julier and J. K. Uhlmann, “New extension of the Kalman filter to nonlinear systems,” in *Proceedings of SPIE*, 1997, vol. 3068, pp. 182-193.

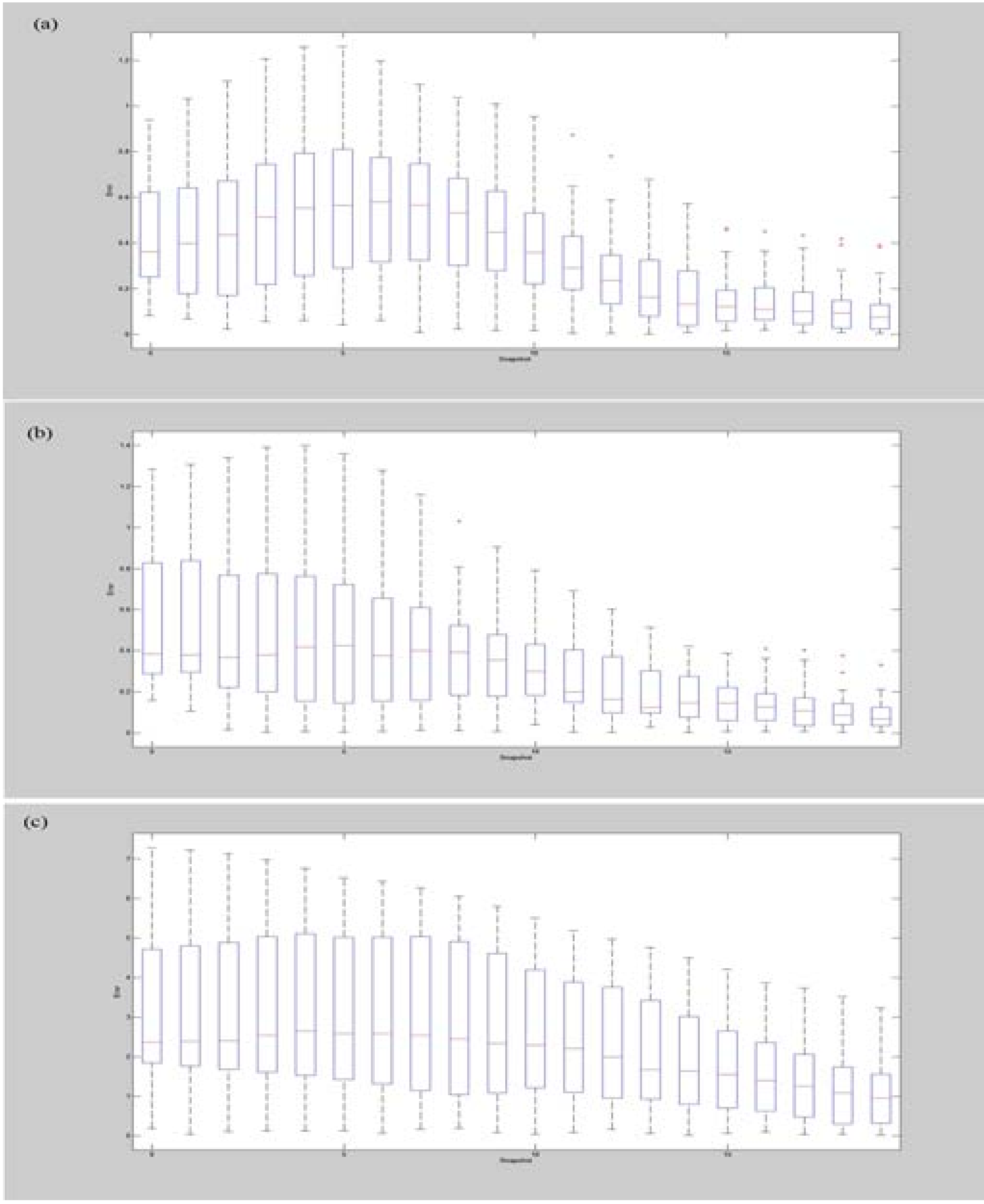


Figure 8. (a) Temperature reconstruction error statistics. (b) Reconstruction error statistics for the wind velocity's amplitude. (c) Reconstruction error statistics for of the wind velocity's angle.

Travel

Sam Atwood arrived in Monterey on June 3 and reported to NRL shortly thereafter. He is working at the lab under the direction of Dr. Jeff Reid for the summer.

Prof. Steve Reising traveled to Norman, Oklahoma June 13-15.

Xavier Bosch-Lluis and Swaroop Sahoo traveled to the Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Central Facility near Lamont, Oklahoma from June 13-15.

Equipment/systems status

Nothing to report this period.

Research Theme: Remote Sensing of Battlespace Parameters

Administrative

Eric Guillot has decided to leave the PhD program at the Colorado State University Department of Atmospheric Science to take a position as an Associate Scientific Analyst with Science Systems & Applications, Inc. (SSAI). SSAI is a contractor to the National Environmental Satellite, Data, & Information Service's (NESDIS) Satellite Analysis Branch (SAB) at the World Weather Building in Camp Springs, MD. The last day of Eric's appointment was June 30.

Research activity and/or results

Dr. Stanley Kidder

Attended a follow-up meeting (April 4) to the CG/AR Annual Review to discuss the upcoming year's activities.

Worked with John Forsythe and University of Michigan colleagues Dorit Hammerling and Yoichi Shiga to experiment with universal kriging as a technique to blend various Total Precipitable Water observations and to extract uncertainty estimates (Figure 9). These are very preliminary results, but the technique looks promising.

Eric Guillot

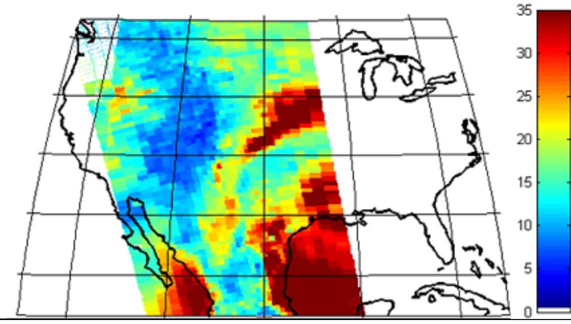
Submitted the manuscript based on his masters research to *Weather and Forecasting*. It was accepted pending major revisions, which were completed and re-submitted. Began new research with Don Reinke to investigate global cloud-free-line-of-sight (CFLOS) information and the existence of cloud-free-vaults (CFVs) using CloudSat.

Cindy Combs

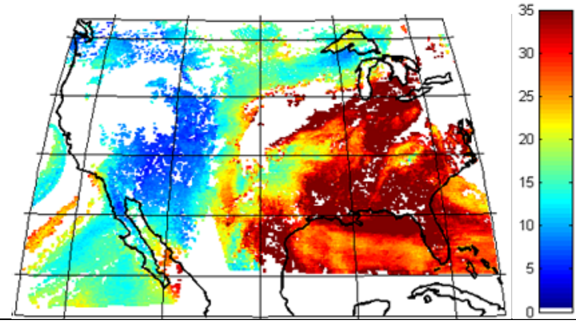
Data for test cases to cover Hurricanes Fay (August 2008) and Bill (August 2009) were set up for the ACAPS project. Pulled quality controlled GOES East data over the eastern CONUS sector from the C3 database for the months of August 2008 and August 2009. This included hourly data from the visible imager channel (channel 1) during daylight hours, and data from the other channels (2,3,4 and 6) for every other hour. Data from channels 1,2, and 4 are at 4x4 km resolution, while data from channels 3 and 6 are at 4x6 km. Also, visible background and cloud percent images for every daylight hour were obtained, as well as statistical products (max, min, standard deviation) from the other channels for every other hour. From this sector, the edges of Fay can be seen by Aug 16 2008, and followed through its path, landfall and remnants through Aug 26. Hurricane Bill only makes a swipe at the east coast. It enters the sector on Aug 21 2009, can see most of it by Aug 22, then is shifts northward and gone by Aug 25. In addition, the same data was obtained from the C3 database for June 2009 for another potential DA study. Data from GOES West over the western CONUS sector was also pulled from the archive for the month for channels 1 (every daylight hour), 2-5 (every other hour). All three months are currently on the system for easy future access.

Ms. Combs also read and made comments for the PCFLOS proposal for AFWA.

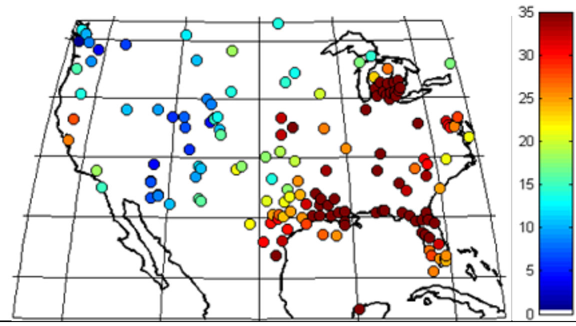
Input #1:
MIRS Total Precipitable Water (mm)



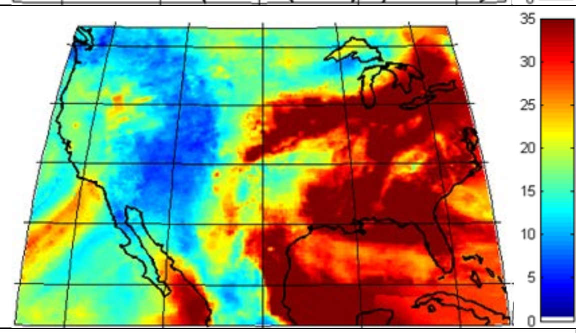
Input #2:
GOES Sounder Total Precipitable Water (mm). White areas are obscured by clouds.



Input #3:
GPS Total Precipitable Water (mm)



Output #1:
Total Precipitable Water (mm) produced by universal kriging of the above three input fields.



Output #2:
Uncertainty estimate produced by universal kriging (mm). Note change of scale.

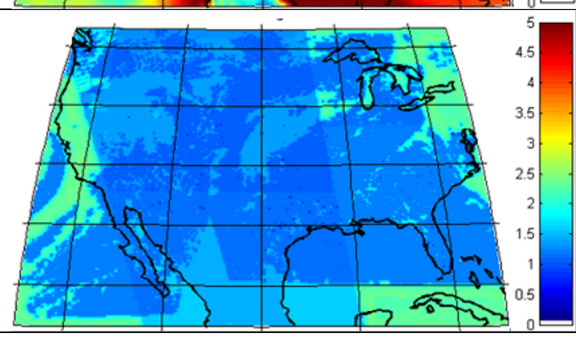


Figure 9. Experiments in the use of kriging as a blending method.

Prof. William Cotton
The journal paper derived from Geoffrey Krall's MS thesis was submitted to Atmospheric Chemistry and Physics.

Prof. Susan van den Heever and Robert Seigel
The first draft of mineral dust ingestion manuscript has been the main focus this quarter. Three core simulations have been completed to understand how dust becomes entrained into convection within different dust regimes: 1) Background dust ingested into a supercell, 2) Dust lofted by a supercell and ingested into the parent supercell, and 3) Dust lofted by both a supercell and an interacting surface boundary and ingested into the parent supercell. Results from these simulations show dramatically different ingestion pathways, which speaks to the need for realistic dust representations. This manuscript is close to submission quality and will be submitted to the Journal of Atmospheric Science.

Originating as a class project for ATS730 (Mesoscale Modeling), Rob is working on an additional manuscript that investigates density currents propagating beneath thin stably stratified layers. Rob built the model used for this numerical experiment during ATS730 and the results are important for understanding the dynamics of density currents within atmospheres similar to dust storm events. It is hypothesized that a density current, similar to a haboob, will accelerate when it encounters a thin stable layer near its top. These results could be important for forecasting dust events, as a better understanding of propagation speed could increase warning time. This paper will be submitted to Monthly Weather Review.

Lance Vanden Boogart
Prof. Vonder Haar and I have been meeting to pin down what my thesis research will center around and have narrowed it down to some type of water vapor analysis. Working with John Forsythe with some CIRA TPW products, and will continue this into the summer. Also, I have been coding extensively in IDL, getting familiar with its inner workings as this is my main tool I plan to use for data analysis. My applied statistics class this past spring semester has been very helpful in furthering my IDL skills.

Travel

None this period.

Equipment/systems status

Nothing to report this period.

Research Theme: Technology Transition and Interactions

Andy Jones presented via telecon on May 18 "CSU CG/AR MyWIDA-Log Java "Ponding" Implementation" at the MyWIDA Workshop, held at the Army Research Laboratory, White Sands Missile Range, New Mexico.

Professor Jeffrey Niemann presented "A Model for Downscaling Soil Moisture Patterns Based on Topography," co-authored by M.L. Coleman, at the USACOE Engineering Research and Development Center.

A poster of the current work of Drs. Y-J Noh and Curtis Seaman was presented at the 2011 Joint CALIPSO-CloudSat Science Team Meeting in mid-June in Montreal.

Prof. Reising presented a talk entitled "Measurement of Water Vapor Density Variations with Fine-Scale Spatial and Temporal Resolution using a Network of Ground-Based, Compact Microwave Radiometers" as the National Weather Center Seminar at the University of Oklahoma and NOAA's National Severe Storms Laboratory (NSSL), Norman, Oklahoma on June 14. He also discussed research collaboration on HUMEX11 with Dr. David Turner of NOAA NSSL during his visit to the National Weather Center.

Appendix 1
CG/AR Researchers under Cooperative Agreement W911NF-06-2-0015

Last Name	First Name	Department	E-mail	Specialty	Theme Area
Azimi-Sadjadi	Mahmood	ElecCompEngr	azimi@engr.colostate.edu	Neural Net Studies/Acoustics	Remote Sensing Battlespace/Urban BL
Carey	Lawrence	TAMU (sub)	carey@ariel.met.tamu.edu	Radar Meteorology/Cloud Microhysics	Clouds, Icing, and Aerosols Effects
Cheng	William	Atmos Science	cheng@atmos.colostate.edu	Mesoscale Modeling	Environmental Modeling and Assimilation
Combs	Cindy	CIRA	combs@cira.colostate.edu	Satellite/Climatology	Hydrometeorology/Battlespace Parameters
Cotton	William	Atmos Science	cotton@isis.atmos.colostate.edu	Atmospheric Modeling	Env Modeling/Battlespace Parameters
Eis	Kenneth	CIRA	eis@cira.colostate.edu	Satellite Meteorology	Technology Transition and Interactions
Fletcher	Steven	CIRA	fletcher@cira.colostate.edu	Data Assimilation Methods	Environmental Modeling and Assimilation
Forsythe	John	CIRA	forsythe@cira.colostate.edu	Satellite Meteorology/Data Analysis	Remote Sensing of Battlespace Parameters, Clouds, Icing, and Aerosols Effects
Fowler	Laura	CIRA	fowler@cira.colostate.edu	Cloud Microphysics/Data Assimilation	Environmental Modeling and Assimilation
Haynes	John	CIRA	haynes@cira.colostate.edu	Satellite Meteor/Cloud Precip Retrievals	Clouds, Icing, and Aerosols Effects
Jones	Andrew	CIRA	jones@cira.colostate.edu	Surface Moisture/Remote Sensing	Hydrometeorology, Environmental Modeling and Assimilation
Julien	Pierre	Civil Env Engr	pierre@lance.colostate.edu	Hydrology	Hydrometeorology
Kankiewicz	Adam	CIRA	kankie@cira.colostate.edu	Satellite Meteorology	Clouds, Icing, and Aerosols Effects
Kidder	Stanley	CIRA	kidder@cira.colostate.edu	Satellite Meterology/Remote Sensing	Remote Sensing of Battlespace Parameters
Knaff	John	CIRA	knaff@cira.colostate.edu	Tropical Met/Forecast Tech Develop	Remote Sensing of Battlespace Parameters
Kreidenweis	Sonia	Atmos Science	soniak@aerosol.colostate.edu	Aerosols	Clouds, Icing, Aerosols Effects/Urban BL
Larson	Vincent	UW-Mil (sub)	vlarson@uwm.edu	Cloud Modeling and Parameterization	Clouds, Icing, and Aerosols Effects
Longmore	Scott	CIRA	longmore@cira.colostate.edu	Modeling and Remote Sensing	Hydrometeorology/Environ. Modeling
Matsumoto	Cliff	CIRA	cliff.r.matsumoto@noaa.gov	Tropical Meteorology/Hurricane Motion	Technology Transition and Interactions
Miller	Steven	CIRA	miller@cira.colostate.edu	Satellite Instrumentation	Clouds, Icing, and Aerosols Effects
Niemann	Jeffrey	Civil Env Engr	jniemann@engr.colostate.edu	Hydrology/Soil Moisture	Hydrometeorology
Noh	Yoo-Jeong	CIRA	noh@cira.colostate.edu	SatMet/Cloud, Precipitation Retrievals	Clouds, Icing, and Aerosols Effects
Ostashev	Vladiimir	CU (sub)	vladimir.ostashev@noaa.gov	Atmospheric Acoustics	Remote Sensing of Battlespace Parameters
Pielke	Roger	CU (sub)	pielkesr@cires.colorado.edu	Mesoscale/Regional Wx Climate Studies	Urban and Boundary Layer Environment
Ramirez	Jorge	Civil Env Engr	ramirez@engr.colostate.edu	Hydrology, Hydrometeorology & Water	Hydrometeorology
Reinke	Donald	CIRA	reinke@cira.colostate.edu	Satellite Meteorology/Programming	Clouds, Icing, and Aerosols Effects
Reising	Steven	ElecCompEngr	steven.reising@colostate.edu	Boundary Layer/Remote Sensing	Urban and Boundary Layer Environment
Sengupta	Manajit	CIRA	sengupta@cira.colostate.edu	Radiative Transfer	Environmental Modeling and Assimilation
Stokowski	David	CU (sub)	david.stokowski@colorado.edu	Look-up Tables	Urban and Boundary Layer Environment
van den Heever	Susan	Atmos Science	sue@atmos.colostate.edu	Atmospheric Modeling/Cloud Physics/StormDynamics	Remote Sensing of Battlespace Parameters
Vonder Haar	Thomas	CIRA	vonderhaar@cira.colostate.edu	Satellite Meteorology	Technology Transition and Interactions
Zupanski	Dusanka	CIRA	zupanski@cira.colostate.edu	Data Assimilation Methods	Environmental Modeling and Assimilation
Zupanski	Milija	CIRA	zupanskim@cira.colostate.edu	Data Assimilation Methods	Environmental Modeling and Assimilation

CG/AR Graduate Students

Last Name	First Name	Department	E-mail	Theme Area	Advisor	Support
Atwood	Sam	Atmos Science	satwood@atmos.colostate.edu	Clouds, Icing, and Aerosols Effects/ Urban and Boundary Layer Environment	Kreidenweis	CG/AR
Busch	Frederick	Civil Environ Engr	frederick.busch@colostate.edu	Hydrometeorology	Niemann	
Coleman	Michael	Civil Environ Engr	mike.coleman@colostate.edu	Hydrometeorology	Niemann	CG/AR
Donofrio	Kevin	Atmos Science	donofrio@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	CG/AR
Fidrych	Jonathan	Elect/Comp Engr	jonmfid@goku.engr.colostate.edu	Advanced Neural Net Processing of Acoustic Data	Azimi	CG/AR
Fields	Christopher	Civil Environ Engr	cmfields@engr.colostate.edu	Hydrometeorology	Niemann	CG/AR
Guillot	Eric	Atmos Science	guillot@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	
Halgren	James	Civil Environ Engr	james.halgren@colostate.edu	Hydrometeorology	Julien	CG/AR
Howell	Kelly	Atmos Science	howell@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	
Johnson	Kelley	Atmos. Science	kcjohnso@lamar.colostate.edu	Clouds, Icing, and Aerosols Effects	Kreidenweis	CG/AR
Kolouri	Soheil	Elect/Comp Engr	soheil.kolouri@colostate.edu	Urban and Boundary Layer Environment	Azimi	CG/AR
Krall	Geoffrey	Atmos Science	gkrall@atmos.colostate.edu	Environmental Modeling and Assimilation	Cotton	CG/AR
Leoncini	Giovanni	Atmos Science	leoncini@atmos.colostate.edu	Boundary Layer and Urban Studies	Pielke	CG/AR
Masarik	Matt	Atmos Science	mmasarik@atmos.colostate.edu	Environmental Modeling and Assimilation	Schubert/Vonder Haar	CG/AR
McCarron	Mike	Elect/Comp Engr	michael.mccarron@colostate.ed	Adv Neural Net Processing Acoustic Data	Azimi	CG/AR
Middlekauff	Steven	Civil Environ Engr	(unavailable)	Hydrometeorology	Niemann	CG/AR
Nobis	Timothy	Atmos Science	timothy.nobis@afwa.af.mil	Boundary Layer and Urban Studies	Pielke	AFIT
Potter	Lauren	Atmos Science	lepotter@atmos.colostate.edu	Urban and Boundary Layer Environment	Kreidenweis	
Ram	Jessica	Atmos Science	ram@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	
Rapp	Dustin	Atmos. Science	rapp@cira.colostate.edu	Soil Moisture WindSat	Vonder Haar	CG/AR
Roy	Gavin	Atmos. Science	gavin.roy@colostate.edu	Urban and Boundary Layer Environment	Vonder Haar	CG/AR
Sahoo	Swaroop	Elect/Comp Engr	swaroop.sahoo@colostate.edu	Urban and Boundary Layer Environment	Reising	CG/AR
Seaman	Curtis	Atmos Science	seaman@cira.colostate.edu	Clouds, Icing, and Aerosols Effects	Vonder Haar	CG/AR
Schwartz	Aaron	Atmos Science	schwartz@cira.colostate.edu	Clouds, Icing, and Aerosols Effects	Vonder Haar	CG/AR
Seigel	Robert	Atmos Science	rseigel@atmos.colostate.edu	Remote Sensing of Battlespace Parameters	van den Heever	CG/AR
Shah	Seema	Civil Environ Engr	sshah@engr.colostate.edu	Hydrometeorology	Julien	CG/AR
Smith	Michael	Atmos Science	msmith@atmos.colostate.edu	Environmental Modeling and Assimilation	Cotton	CG/AR
Wichern	Gordon	Elect/Comp Engr	gwichern@engr.colostate.edu	Adv Neural Net Processing Acoustic Data	Azimi	CG/AR

Appendix 2
Publications

(The following were supported under CG/AR Cooperative Agreement W911NF-06-2-0015. Readers may also want to review the publications list from the previous Cooperative Agreements, DAAD19-02-2-0005, DAAD19-01-2-0018 and DAAL01-98-2-0078.)

Carey, L.D., J. Niu, P. Yang, J.A. Kankiewicz, V.E. Larson, and T.H. Vonder Haar, 2008: The vertical profile of liquid and ice water content in midlatitude mixed-phase altocumulus clouds. *J. Appl. Meteor. Clim.*, 47, 2487-2495 (doi: 10.75/2008JACM885.1).

Combs, C.L., D. Rapp, A.S. Jones, and G. Mason, 2007: Comparison of AGRMET model results with *in situ* soil moisture data. Pre-print CD-ROM, 21st Conference on Hydrology, January 14-18, San Antonio, TX (AMS).

Donofrio, K.M., 2007: A 1DVAR optimal estimation retrieval of water vapor profiles over the global oceans using spectral microwave radiances. Masters thesis, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, 165 pp.

Fletcher, S.J., 2010: Mixed Gaussian-lognormal four-dimensional data assimilation. *Tellus,* 62A, 266-287.

Fletcher, S.J., and M. Zupanski, 2007: An alternative to bias correction in retrievals and direct radiances assimilation. Pre-print CD-ROM, 11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), January 13-19, San Antonio, TX (AMS).

Fletcher, S.J., M. Zupanski, and T.H. Vonder Haar, 2007: Lognormal Data Assimilation: Theory and Applications. Proceedings CD, Battlespace Atmospheric and Cloud Impacts on Military Operations Conference (BACIMO) 2007, November 6-8, Chestnut Hill, MA. Oral presentation, Session 2: Data Assimilation and Numerical Modeling.

Fletcher, S.J., and M. Zupanski, 2007: Implications and impacts of transforming lognormal variables into normal variables in VAR. *Meteorolgische Zeitschrift*, 16, 755-765.

Fletcher, S.J., and M. Zupanski, 2008: A study of ensemble size and shallow water dynamics with the Maximum Likelihood Ensemble Filter. *Tellus,* 60A, 348-360.

Forsythe, J.M., S.Q. Kidder, A.S. Jones, and T.H. Vonder Haar, 2007: Moisture profile retrievals from satellite microwave sounders for weather analysis over land and ocean. Proceedings (CD-ROM), The Joint 2007 EUMETSAT Meteorological Satellite Conference and the 15th American Meteorological Society (AMS) Satellite Meteorology and Oceanography Conference, September 24-28, Amsterdam, The Netherlands.

Forsythe, J.M., E.M.Guillot, and T.H. Vonder Haar, 2010: Improving cloud Nowcasting with satellite imagery via incorporation of cloud type. 14th Conference on Aviation, Range, and Aerospace Meteorology, January 17-21, Atlanta, GA (AMS) (poster).

Gaiser, P., A. Jones, L. Li, G. Mason, G. McWilliams, M. Mungiole, 2007: Improving the effectiveness of determining soil moisture using passive microwave satellite imagery. White paper to the National Polar-orbiting Operational Environmental Satellite Systems (NPOESS) Integrated Program Office (IPO), 14 pp.

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